Tropical Cyclone Structure and Intensity Change

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LONG-TERM GOALS

The long-term goals of our research are to understand the interactions between tropical cyclones and their surroundings, and how such interactions influence tropical cyclone structure and intensity change.

OBJECTIVES

During the two-year proposal, this work had two primary objectives: (i) to understand the interactions of upper tropospheric potential vorticity centers and tropical cyclones and the intensity changes that occur during such interactions; and (ii) to study the larger scale influences on the generation of tropical cyclones in the eastern and western Pacific Oceans. The first of these is an extension of previous work under ONR support, while the second is a newer initiative, particularly the western Pacific studies.

APPROACH

The first objective has been approached by two types of observational studies using gridded analyses from the European Centre for Medium Range Weather Forecasting (ECMWF): individual case studies and composite studies. The second objective has made use of gridded analyses from the ECMWF and by gridded analyses of outgoing longwave radiation (OLR). Both have been low-pass and band-pass filtered where appropriate.

Graduate students Anantha Aiyyer, Deborah Hanley, and Michael Dickinson and research associate David Vollaro have worked on various aspects of the problem.

WORK COMPLETED

The first three pieces of work discussed below relate to studies of tropical cyclone-trough interactions. The paper by Molinari et al. (1998) analyzed the intensification of Hurricane Danny (1985) during interaction with an upper tropospheric trough. This was discussed in last year's report and will not be discussed further.

Debbie Hanley completed her PhD entitled "The Effect of Trough Interactions on Tropical Cyclone Intensity Change". In this work Debbie examined a large number of cases of tropical cyclone-trough interactions, and constructed six tropical cyclone-centered composite interactions: (i)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Tropical Cyclone Structure and Intensity Change	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Albany/Suny,Department of Earth and Atmospheric Sciences,1400 Washington Avenue,Albany,NY,12222**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

favorable (meaning the tropical cyclone intensifies during interaction) superposition cases; (ii) favorable "distant interaction" (i.e., non-superposition) cases, where the upper trough did not approach to within 500 km of the tropical cyclone); (iii) favorable extratropical transition; (iv) favorable no trough (intensification when no upper PV anomaly was present); (v) unfavorable no trough; and (vi) unfavorable with trough.

A paper entitled "Environmental Influences on the Rapid Intensification of Hurricane Opal (1995) over the Gulf of Mexico" was accepted by *Monthly Weather Review*. This work describes the influences of a trough interaction, a warm eddy in the ocean, and internal dynamics during the intensification and weakening of Hurricane Opal.

The remaining pieces of work relate to the generation of tropical cyclones and related large scale influences. PhD student Michael Dickinson has submitted a paper to *Monthly Weather Review* entitled "Climatology of Sign Reversals of the Meridional Potential Vorticity Gradient over Africa and Australia". This work compares the diabatic generation of sign reversals of the meridional potential vorticity gradient over Africa, where they are known to influence tropical cyclogenesis downstream, and over Australia, where they have not been previously described. As part of his PhD work, Michael Dickinson is also examining a case study where two tropical cyclones form in rapid succession in the western Pacific.

The paper "Potential Vorticity, Easterly Waves, and Eastern Pacific Tropical Cyclogenesis", by Molinari, Knight, Dickinson, Vollaro, and Skubis, appeared in the *Monthly Weather Review*. This paper was discussed in last year's report.

A paper entitled "Origins and Mechanisms of Eastern Pacific Tropical Cyclogenesis: A Case Study" has accepted by *Monthly Weather Review* and will appear in the January 2000 issue. This work describes the large-scale influences on the genesis of Hurricane Hernan of 1996 in the eastern Pacific Ocean.

A paper entitled "Planetary and Synoptic Scale Influences on Eastern Pacific Tropical Cyclogenesis" has been submitted to *Monthly Weather Review*. This represents an extension to our 1997 paper on the 1991 season in the eastern Pacific.

RESULTS

Debbie Hanley's composites during trough interactions have shown that relatively small scale, shallow upper PV anomalies are much more likely to produce tropical cyclone intensification than large, deep anomalies. This result is consistent with PV inversion reasoning and with our previous case studies. The "distant interaction" cases show the tropical cyclone embedded in the entrance region of an upper jet streak. Intensification appears to occur as a result of the superposition of upward motion associated with the jet over the storm. Debbie also examined a climatology of intensity changes during trough interactions. She found that although tropical cyclones intensify less often during trough interactions than they do when no trough is present, two thirds of tropical cyclones (when cold-water cases are omitted) do intensify during such interactions. This intensification occurs despite a vertical wind shear that has nearly twice the magnitude of the climatological value at the same location. The results show that upper troughs bring both increased wind shear and favorable radial-vertical circulations during interaction, and that it is the opposing influences of these two factors that determine the outcome.

The Hurricane Opal paper results provided support for our previous theories, and extended them to include the influence of sea surface temperature variations and inner core response to the upper tropospheric trough. Opal was found to have deepened rapidly as the upper tropospheric divergence field associated with the trough approached the incipient tropical cyclone core. The "warm eddy" in the waters of the Gulf of Mexico contributed, but only after the favorable trough interaction had begun. When the trough axis itself approached the core of Hurricane Opal, the tropical cyclone weakened. This represented an unfavorable trough interaction brought about because the scale of the trough was much larger than that of the tropical cyclone, and thus contained very large vertical wind shear.

The paper "Climatology of Sign Reversals of the Meridional Potential Vorticity Gradient over Africa and Australia" showed that Australia contains a sign reversal similar in structure and magnitude to that in Africa, but of somewhat smaller zonal extent. Both sign reversals are generated by a combination of deep convective heating (estimated using OLR data) on the equatorward side, and shallow convective heating on the poleward side. Easterly wave growth in the sign reversal region is much better defined over Africa than over Australia.

The paper "Origins and Mechanisms of Eastern Pacific Tropical Cyclogenesis: A Case Study" found that Hurricane Hernan (1996) developed in association with a wave in the easterlies that could be tracked back to Africa. A dynamically unstable background state accompanied the growth of the wave, which crossed central America at levels just above the mountain tops. A tropical depression formed underneath the wave just west of the Gulf of Tehuantepec. The results provide strong support in this case study for an African origin to eastern Pacific disturbances; development in the eastern Pacific clearly occurred in association with this wave from upstream.

The paper "Planetary and Synoptic Scale Influences on Eastern Pacific Tropical Cyclogenesis" addressed the role of the Madden-Julian oscillation (MJO) on eastern Pacific cyclogenesis during the 1991 season, when long-period oscillations in storm formation were prominent. It was shown that the formation of storms was enormously influenced by the MJO. During each active MJO period, storms tended to form first well east and south, then progressively further westward and northward with time. The results showed that cyclogenesis occurred when easterly waves from upstream passed through the convectively active phase of the MJO. Waves were present in equal numbers, but did not develop, during the inactive MJO phase.

Michael Dickinson's work in the western Pacific will likely become the major contribution of his PhD work. Three figures are presented below that summarize the current progress. Figure 1 shows a Hovmoeller diagram of the bandpass-filtered (2-10 day) v component of the wind along the equator in the western Pacific. Between 11 and 26 July 1987 three cycles appear of what is almost certainly a mixed Rossby-gravity (MRG) wave. It has a phase velocity of -7 ms^{-1} (with respect to the ground) and an equally clear group velocity of about +1 ms^{-1}. Figure 2 shows on 11 July a plot of 2-10 day v and OLR. It can be seen that the OLR, despite its complexity, has a clear MRG wave signature, with enhanced convection north of the equator when the equatorial flow is from the south, and south of the equator when it is from the north. It is apparent from this and other daily maps (not shown) that this wave moves westward with time, then curves northwestward. A tropical cyclone forms in the cyclonic portion of the MRG wave, where initially no convection is present. The same sequence of events occurs in the subsequent MRG wave. In each case the convection shifts from the MRG structure seen in Figure 2 to a convective maximum directly over

the region of large cyclonic vorticity, i.e., characteristic of a more traditional easterly wave. We have the following working hypothesis: the original MRG waves are refracted out of the equatorial latitudes as they grow in amplitude; Ekman pumping can occur off the equator, and a tropical disturbance, eventually a typhoon, forms in the region of strongest cyclonic vorticity. It is apparent from Figure 2 that the wave still has structure at higher latitudes, so that we believe wave dynamics is still relevant. Figure 3 shows the lowpass-filtered background OLR (20 day half power point) superimposed on the 2-10 day *v* component at the same time as Figure 2. The presence of a well-defined MJO event in this background OLR is apparent. Remarkably, the propagation and growth of the waves seems to follow closely the convective envelope of the MJO. This work will be continued in the next year.

IMPACT/APPLICATIONS

The tropical cyclone-trough interaction studies have great potential for development of operational criteria for prediction of tropical cyclone intensity during such interactions. This remains one of the major goals of our studies. We believe the single most important variable in whether a trough interaction will produce deepening of a tropical cyclone is the horizontal scale of the trough: a large trough contains too much vertical shear and is unfavorable; a small-scale trough (300-400 km in diameter) allows a favorable superposition between the two positive potential vorticity anomalies (trough and tropical cyclone).

We believe that the Pacific studies of cyclogenesis provide some evidence concerning why clusters of tropical cyclones tend to form in time, followed by quiet periods. The relationship of the MJO and cyclogenesis is well-known. Our work adds to this the role of meridional PV gradient sign reversals, and the growth of waves from upstream in the active MJO region, in repeated cyclogenesis. In addition, we view the case study of the apparent origin of some western Pacific disturbances from MRG waves as a significant finding, and to our knowledge, the first synoptic case study of an equatorial wave that leads to subsequent tropical cyclogenesis.

There is currently a fair amount of controversy over the role of easterly waves in tropical cyclogenesis in the western Pacific. To the extent that the above events are common, which remains to be determined, it is notable that MRG waves do not have a typical easterly wave signature, but rather an equatorial wave signature in convection. They may thus not be easily trackable in satellite pictures by traditional methods, and this may contribute to the opinion of many scientists that waves in the easterlies are unimportant. Over the next year we will expand our studies to examine the frequency of such MRG wave events, and in general the extent to which western Pacific cyclogenesis is associated with some type of pre-existing disturbance in the easterlies.

TRANSITIONS

The studies on trough interactions have implications for the operational prediction of tropical cyclone intensity, which remains in its infancy. The studies on Pacific tropical cyclogenesis raise the possibility of identifying active periods of tropical cyclone formation several days in advance.

RELATED PROJECTS

We are conducting a study under NSF support of easterly wave dynamics in the Atlantic. In concert with Professor Bosart of my department, I am working on hurricane-trough interactions and precipitation after landfall as part of the US Weather Research Project. Lance Bosart, Peter Black of NOAA/HRD, Chris Velden of the University of Wisconsin, PhD student Edward Bracken of SUNYA, and I collaborated on the study of the unexpected intensification and later weakening of Hurricane Opal as it approached the Gulf coast. Dan Keyser of my department was a co-advisor for Debbie Hanley's PhD studies.

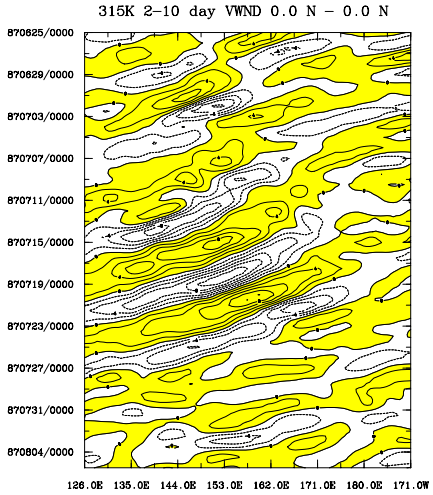

Figure 1

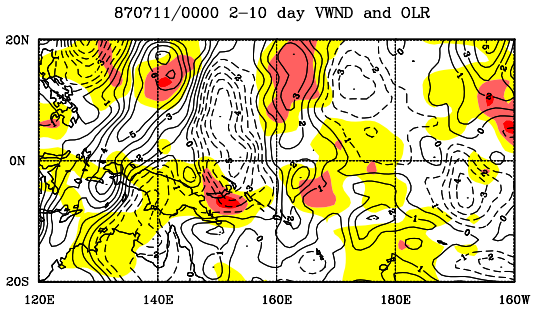

Figure 2

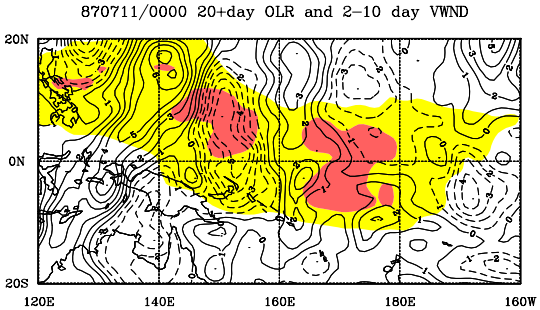

Figure 3

REFERENCES

Hanley, D., 1999: The Effect of Trough Interactions on Tropical Cyclone Intensity Change. PhD Dissertation, Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, 164 pp.

Aiyyer, A., 1998: Interaction of tropical cyclone outflow layer potential vorticity anomalies. M.S. Thesis, Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, 180 pp.

Aiyyer, A., and J. Molinari, 1999: Idealized modelling of hurricane-trough interactions in the outflow layer. 23nd Conference on Hurricanes and Tropical Meteorology, Dallas, TX, 11-15 January.

Hanley, D., 1999: The effect of trough interactions on tropical cyclone intensity change. 23nd Conference on Hurricanes and Tropical Meteorology, Dallas, TX, 11-15 January.

Dickinson, M., 1999: Global climatology of sign reversals of the meridional potential vorticity gradient. 23nd Conference on Hurricanes and Tropical Meteorology, Dallas, TX, 11-15 January.

Hanley, D., J. Molinari, and D. Keyser, 2000: A comparison of favorable and unfavorable trough interactions. 24th Conference on Hurricanes and Tropical Meteorology, Fort Lauderdale, FL.

Dickinson, M., 2000: Mixed Rossby-gravity waves and western Pacific tropical cyclogenesis. 24th Conference on Hurricanes and Tropical Meteorology, Fort Lauderdale, FL.

Molinari, J., D. Vollaro, S. Skubis, and M. Dickinson, 1999: Eastern Pacific tropical cyclogenesis. 23nd Conference on Hurricanes and Tropical Meteorology, Dallas, TX, 11-15 January.

Molinari, J., D. Vollaro, M. Dickinson, and A. Aiyyer, 2000: Easterly waves and tropical cyclogenesis. 24th Conference on Hurricanes and Tropical Meteorology, Fort Lauderdale, FL.

PUBLICATIONS

Molinari, J., and D. Vollaro, 2000: Planetary and synoptic scale influences on eastern Pacific tropical cyclogenesis. *Monthly Weather Review*, submitted.

Dickinson, M.J., and J. Molinari, 2000: Climatology of sign reversals of the meridional potential vorticity gradient over Africa and Australia. *Monthly Weather Review*, submitted.

Molinari, J., D. Vollaro, S. Skubis, and M. Dickinson, 2000: Origins and mechanisms of eastern Pacific tropical cyclogenesis: A case study. *Monthly Weather Review*, January issue.

Bosart, L.F., C.S. Velden, W. E. Bracken, J. Molinari, and P.G. Black, 2000: Environmental influences on the rapid intensification of Hurricane Opal (1995) over the Gulf of Mexico. *Monthly Weather Review*, in press.

Molinari, J., S. Skubis, D. Vollaro, F. Alsheimer, and H. Willoughby, 1998: Potential vorticity analysis of hurricane intensification. *Journal of the Atmospheric Sciences*, **55**, 2632-2644.

Molinari, J., D. Knight, M. Dickinson, D. Vollaro, and S. Skubis, 1997: Potential vorticity, easterly waves, and tropical cyclogenesis. *Monthly Weather Review*, **125**, 2699-2708.

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All of the work is done at the University at Albany, State University of New York.